WORKING PAPER
ALFRED P. SLOAN SCHOOL OF MANAGEMENT

CONNECTIVITY AMONG INFORMATION SYSTEMS

Y. Richard Wang

Stuart E. Madnick

June 1988 #WP 2025-88

MASSACHUSETTS
INSTITUTE OF TECHNOLOGY
50 MEMORIAL DRIVE
CAMBRIDGE, MASSACHUSETTS 02139

CONNECTIVITY AMONG INFORMATION SYSTEMS

Y. Richard Wang

Stuart E. Madnick

June 1988 #WP 2025-88

Connectivity Among Information Systems

Y. Richard Wang

Stuart E. Madnick

SLOAN SCHOOL OF MANAGEMENT, E53-320
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MA 02139
(617) 253-6671

Submitted to CACM, Computing Practice.

June 1988

Table of Contents

Connectivity Among Information Systems

Y. Richard Wang
Stuart E. Madnick
E53-320, MIT
Sloan School of Management
Cambridge, MA 02139
(617) 253-6671

ABSTRACT Many important strategic applications require access to and integration of disparate information resources. We refer to this category of information systems as *Composite Information Systems* (CIS). Issues involved in developing a CIS are categorized and exemplified to reveal the deficiencies of current practice. A methodology which incorporates Data Base Management Systems and Artificial Intelligence techniques is presented. Furthermore, an operational Tool Kit for CIS (CIS/TK) has been implemented. The CIS/TK ensemble consists of four components: knowledge processing, information processing, physical and logical connectivity, and interface tools. It is an innovative system for delivering timely knowledge and information in an inter-organizational setting. In the rapidly changing, complex, and competitive global market, the capability to dynamically align corporate strategy with information technology in the organizational context is a critical issue facing the executive. This methodology and prototype system are specifically aimed at providing a dynamic platform for supporting such knowledge and information intensive applications.

KEY WORDS AND PHRASES: composite information systems, cooperative systems, distributed databases, organizational information systems, systems development.

ACKNOWLEDGEMENTS Work reported herein has been supported, in part, by the Department of Transportation's Transportation System Center, the U.S. Air Force, the U.S. Space and Naval Warfare System Command, Center for Information Systems Research at MIT, and Citibank.

Connectivity Among Information Systems

INTRODUCTION

The rapidly increasing complexity, interdependence, and competition in the global market has profoundly impacted how corporations operate and how they align their information technology (IT) for competitive advantage in the marketplace. This alignment has accelerated demands for more effective information management for decision-making, operational efficiency, and new product and services [5, 21]. Meanwhile, the computing industry has made significant advances in the price, speed performance, capacity, and capabilities of many information technologies over the last two decades. A key concern facing corporations today is how to make most effective use of IT to meet their needs [12, 19].

For example, an on-going dialogue exists between the MIT Sloan School of Management and the sponsors of the *Management in the 1990's* research program. In a recent meeting with the sponsors[1] to assess their information technology requirements for 1995, a critical need was identified for developing systems that can provide access to, and integration of their corporations' numerous information systems, as depicted in Figure 1.

A CIS APPLICATION: PAS

It has become increasingly evident that many important applications require such access to and integration of multiple disparate databases both within and

---

1. The meeting was held at the MIT Sloan School in the late April, 1988. The participants were IT executives from American Express, Arthur Young & Co., Bell South, British Petroleum, Cigna Insurance, Digital Equipment Corporation (DEC), International Computers, Ltd,, Kodak, IRS, and U S. Army.

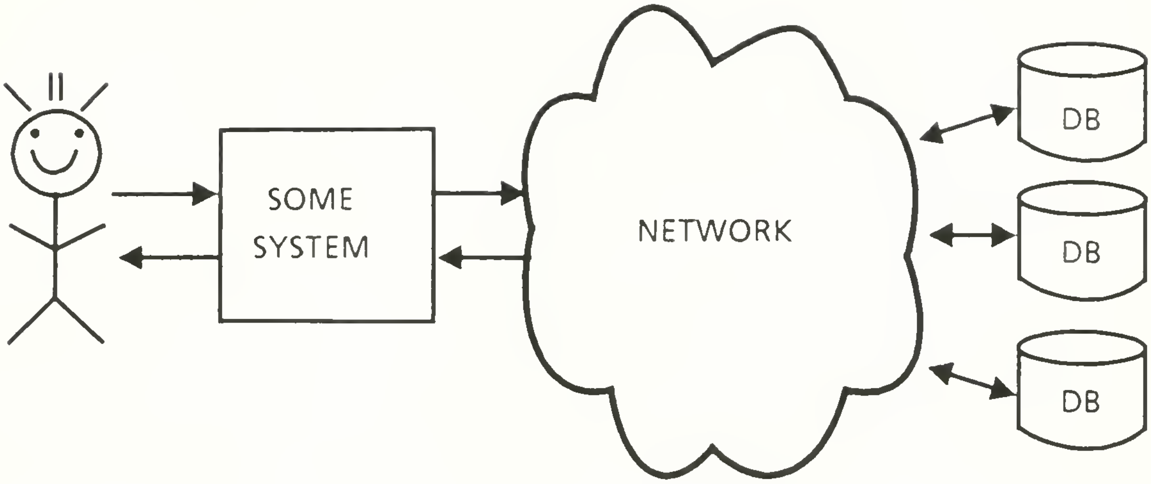

Figure 1 A Perspective of the Information Technology Requirements for 1995

across organizational boundaries in order to increase productivity [4, 9]. We refer to this type of systems as *Composite Information Systems* (**CIS**) [11, 16, 20, 24].

Consider the Placement Assistant System (PAS), depicted in Figure 2, which is being developed for the MIT Sloan Placement Office. PAS spans five information systems in four organizations: (1) the **student database** and the **interview schedule database** are located in the Sloan School; (2) the **alumni database** is located in the MIT alumni office; (3) the *recent news* is accessed by dialing into Reuter's **Textline database**; and (4) the *recent financial information* is accessed through I.P. Sharp's **Disclosure II database**.

An interesting query for PAS to handle would be to "find companies interviewing at Sloan"

- that are *auto manufacturers*,
- the *students* from these companies,
- the *alumni* from these companies,
- recent *financial information*, and
- recent *news* about these companies.

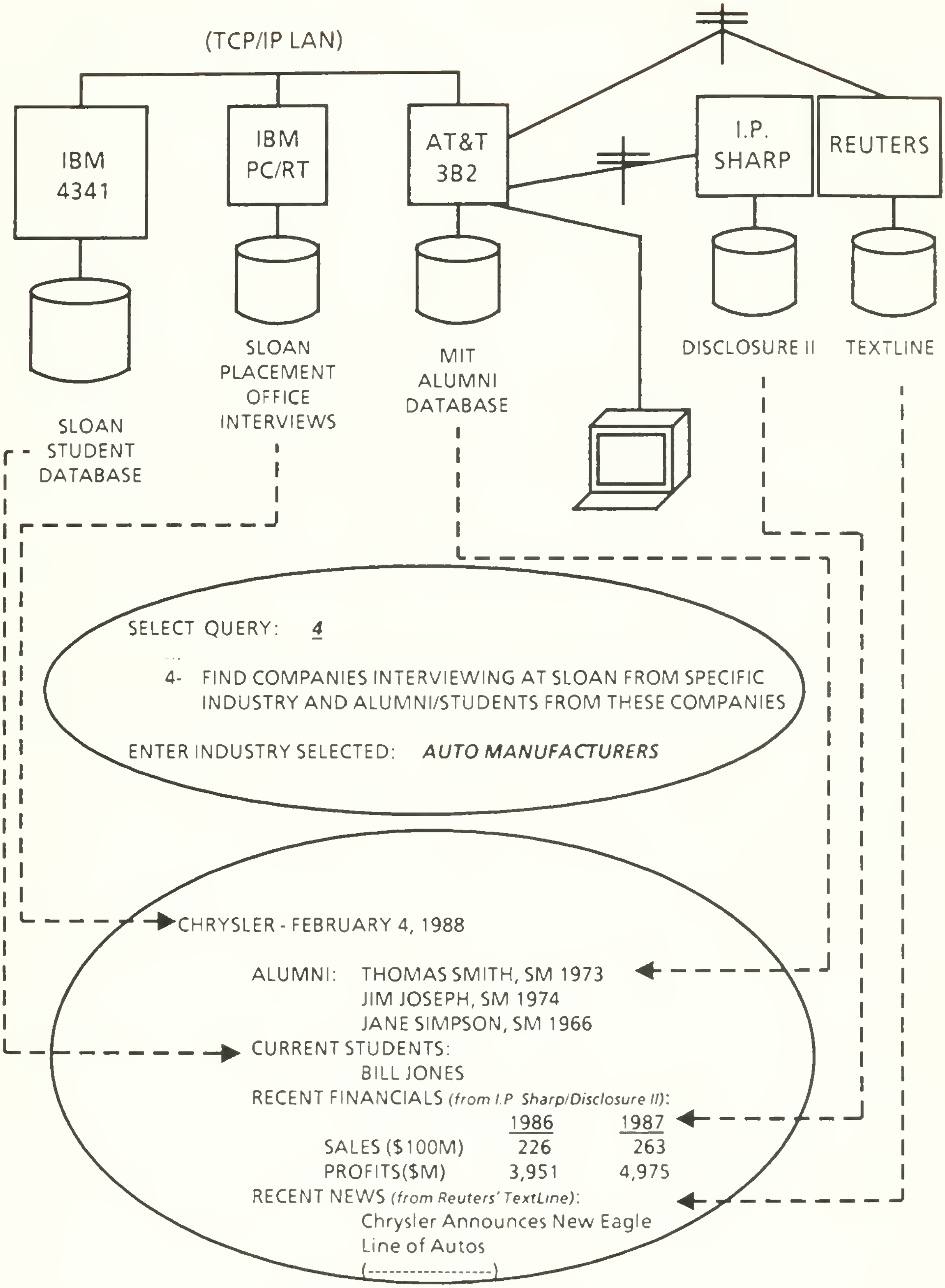

Figure 2 A CIS for the Sloan Placement Office

This information would be very valuable to a student interested in the automobile industry. Current students from these companies can offer first-hand insider information. The alumni from these companies may be able to "put in a good word" on his behalf. Recent financial information indicates the economic environment at that company as well as providing information that may be helpful during an interview. Finally, recent news will keep the student abreast of what is going on in that company as well as to be well prepared for the interview with the recruiters.

Figure 2 depicts a partial menu for the query and its corresponding answer in the case of *Chrysler*. Many research problems need to be solved in order to obtain the composite information for this query. These problems can be categorized into first- and second-order issues, as discussed below.

CONNECTIVITY ISSUES

First Order Issues

The first-order issues are encountered immediately when attempting to provide access to and integration of multiple information resources:

- multi-vendor machines (IBM PC/RT, IBM 4341, AT&T 3B2, etc.)
- physical connection (Ethernet, wide-area net, etc.)
- different databases (ORACLE__SQL, IBM's SQL/DS, flat files)
- information composition (formating)

The issues of multiple vendor machines and physical communication are inherent as long as information resources are dispersed across geographic locations, be they intra- or inter-organizational. For example, the Sloan recruiting database is implemented in an *IBM PC/RT* computer whereas the Sloan alumni database is stored in an *AT&T 3B2* computer. Communication protocols need to be established (e.g., TCP/IP LAN) between different machines for encapsulating the machine idiosyncrasies.

Assuming that hardware idiosyncrasies and networking problems are resolved, the next hurdle is the idiosyncrasies of different databases. For example, the recruiting database is developed in the ORACLE relational database, thus accessed through SQL type queries; whereas I.P. Sharp's Disclosure II financial database is accessed through a menu driven interface. Different query commands and the corresponding skill are required in order to obtain the information available from these various information resources.

Second Order Issues

Suppose that one is able to resolve the above problems, he will nevertheless encounter the information composition task which abounds with second-order issues such as:

- database navigation (where is the data for alumni position, base salary, etc.)
- attribute naming (*company* attribute vs. *comp_name* attribute)
- simple domain value mapping ($, ¥, and £)
- instance identification problem (*IBM Corp* in one database vs. *IBM* in another database)

Database navigation is needed in order to determine which database to access to get the required information. Furthermore, on a menu-driven database, e.g., Reuter's Textline, it is important to know which menu path to access in order to save not only time but also access cost. Similarly, in a relational database system, it is necessary to know in which tables the required data is located (e.g., alumni position, company name) so that appropriate SQL queries can be formulated.

Entity and attribute names may be termed differently among databases, such as company vs. comp_name. This type of issues have been referred as the schema-level integration problem [24]. In addition to the schema level integration, it is necessary to perform mapping at the instance level. For example, sales may be reported in $100 millions, but revenue in $millions. Furthermore, in a multi-national environment, financial data may be recorded in $, ¥, or £ depending on the subsidiary.

The *instance identification* problem becomes critical when multiple independently developed and administered information systems are involved because different identifiers may be used in different databases, e.g., *IBM Corp* vs. *IBM*. In the more complicated cases, no common key identifiers are available for joining the data across databases for the same entity. We refer to these types of second-order issues collectively as *logical connectivity*, as will be elaborated later.

CURRENT PRACTICE

Although many *Composite Information Systems* exist today, most are in reality, a combination of human operators and computer systems. In such a case, the human intervention required to interface multiple independent databases implies that it is an expensive, time-consuming, and error-prone process. For example, a major international bank [9] has developed its bank products (e.g., funds transfer, letter of credit, loans, cash management) autonomously. When information must be exchanged, it was often accomplished by "tape hand-offs", usually at night, as depicted in Figure 3.

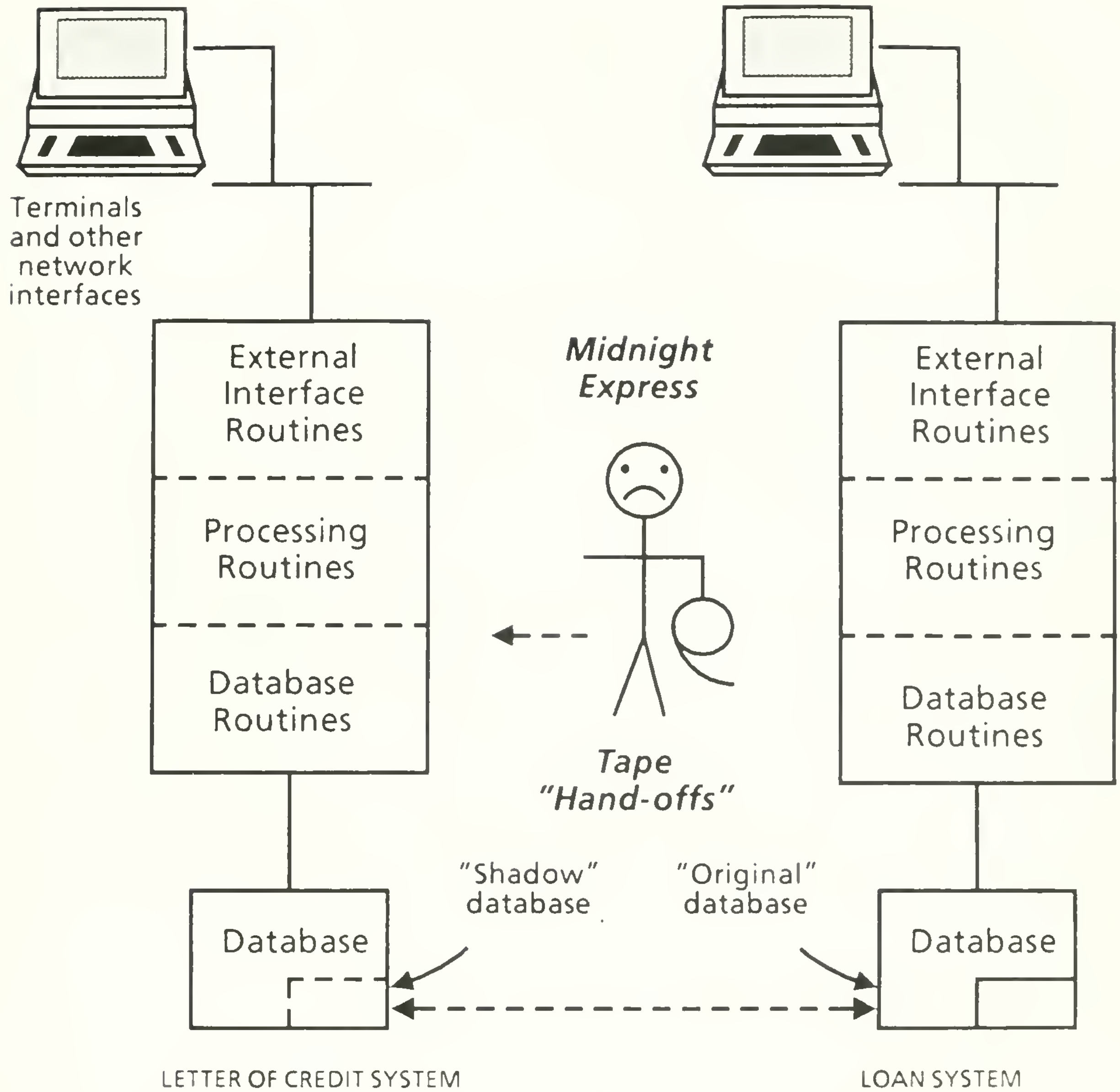

Figure 3 Access Multiple Systems Through Human Operators

On the other hand, the needs for integration have been increasing rapidly both at the user level and database level. Since each system had its own directly connected terminals, users that required access to multiple systems had to have multiple terminals in their office, or walk to an area of the building that had a terminal tied to the system needed. The "tape hand-offs" mechanism was used to create "shadow" databases of each other's real databases (Figure 3). Since the shadow database diverges from the real database during the day, inconsistencies could result.

The problem of integration has been intensified by the need for evolution in at least three areas: current products, new products, and new technology. As the current products become more sophisticated, there is need to acquire more information from other systems. Increasing "tape hand-offs" leads to processing complexities. It would be advantageous if the human operator component could be automated as much as possible.

To improve upon these operational difficulties, more complex systems have been developed that directly tap into multiple information resources [16]. In these cases, the knowledge of the contents of these sources and transformations necessary are encoded into customized programs and are not captured in a manner that allows this knowledge to be easily extended nor used in new ways. The key thrust of the work described in this paper is the ability to capture this knowledge in an easy way and be able to use general-purpose tools that are driven by such a knowledge base to enable rapid, flexible, and extensible development of powerful composite information systems.

SOLUTION APPROACH

Confronted with these problems, we have found it effective to incorporate Artificial Intelligence (AI) technology as part of the solution. AI technology has proven to be very useful in making rule-based inferences. By integrating the information sharing capability of DBMS technology and the knowledge processing power of AI technology [13], multiple independent disparate databases may be accessed in concert with minimum human intervention.

In addressing the integration of AI and DBMS technologies, Albert, Chern, and Sears[2] have suggested that:

> "In the long term, research is needed to find ways for knowledge-based system technology to support database systems and vice versa. In the near term, research is needed to develop tools that support the design and development of systems that require an integrated set of knowledge base and database system tools."

The *Tool Kit for Composite Information Systems* (CIS/TK) is a research prototype being developed at the MIT Sloan School of Management for providing such an integrated set of knowledge base and database system tools. It is implemented in the UNIX environment both to take advantage of its portability across disparate hardware and its multi-programming and communications capabilities to enable accessing multiple disparate remote databases in concert[3]. CIS/TK employs an object-oriented approach and rule-based mechanism, as discussed below.

THE CIS/TK ENSEMBLE

The CIS/TK ensemble can be viewed as a *Knowledge and Information Delivery System* (KIDS), as depicted in Figure 4, which has four functional components: knowledge processing, information processing, physical and logical connectivity, and user interfaces. Specifically, it consists of the following four subsystems:

(1) Knowledge Processing

The knowledge processing subsystem is based on an enhanced version of the Knowledge-Object Representation Language [14] which facilitates an object-

---

2. In the forward of Topics in Information Systems On Knowledge Base Management Systems, Brodie and Mylopoulos, ed., 1986

---

3. The choice of UNIX portability on conventional machines reflects our pragmatic philosophy.

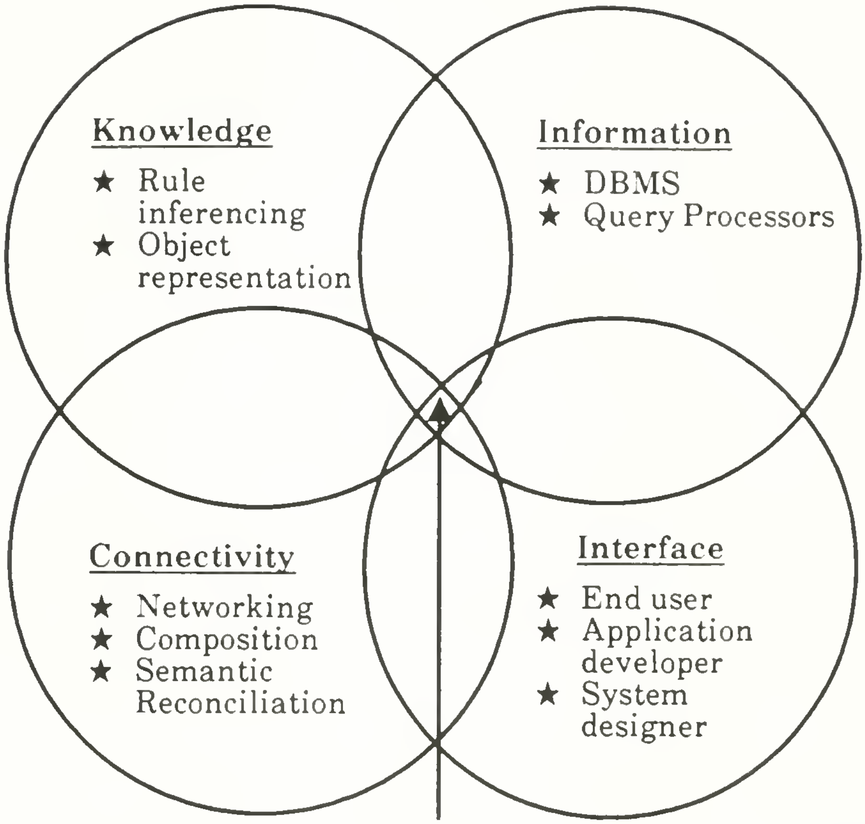

Figure 4 Knowledge and Information Delivery Systems [KIDS]

oriented approach and rule-based inferencing mechanism. This subsystem provides three benefits: (1) it gives us the capability to evolve the code for experimenting and developing innovative concepts; (2) it provides the required knowledge representation and reasoning capabilities for knowledge-based processing in the heterogeneous distributed DBMS environment; and (3) it is very simple to interface with off-the-shelf software products (e.g., ORACLE and INFORMIX) through the I/O redirection and piping capability inherent in the UNIX environment. The reader is referred to Levine [14] for a detailed description of the knowledge processing component.

(2) Information Processing & Physical Connectivity

The CIS/TK query processor architecture is shown in Figure 5. The architecture

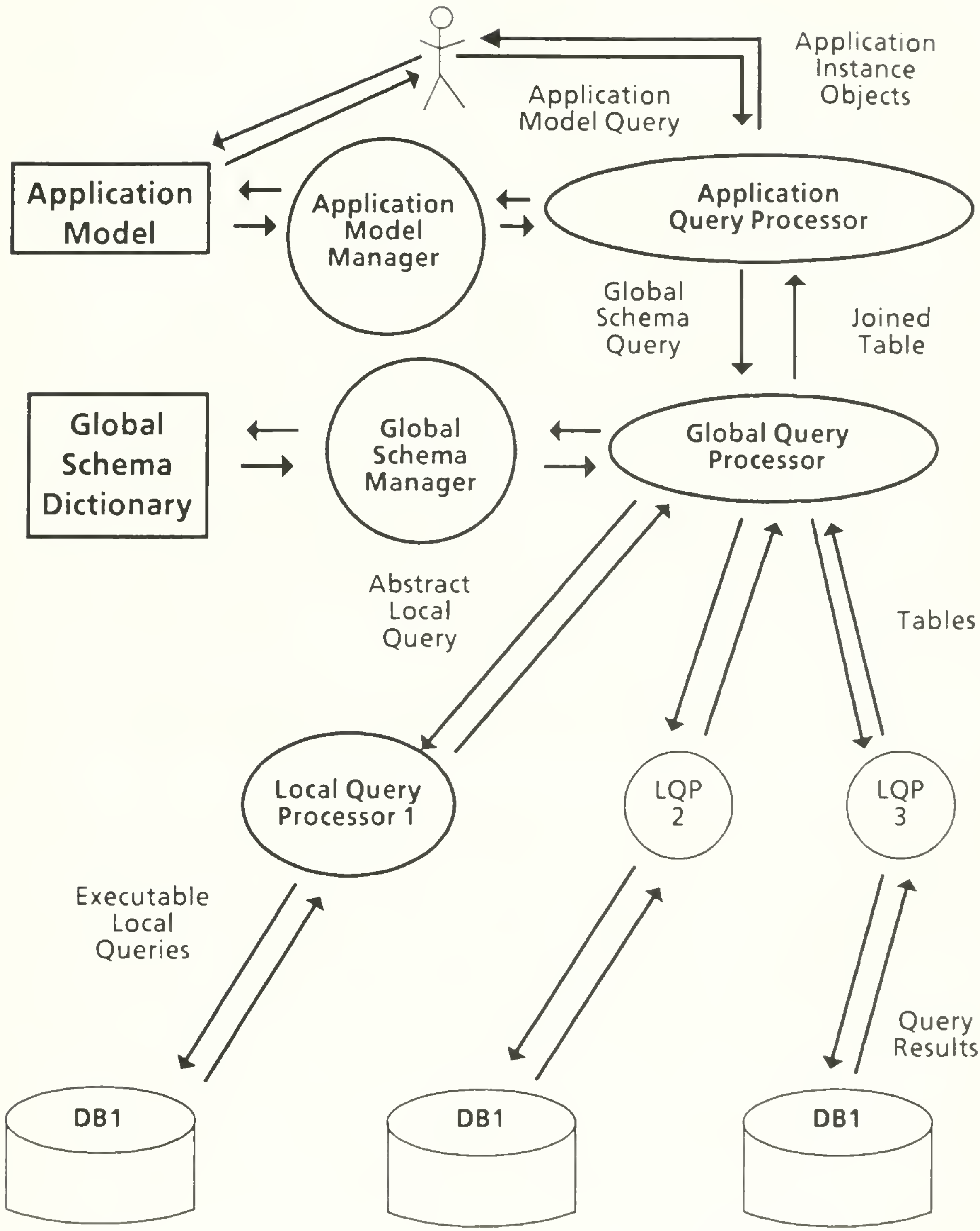

Figure 5 The CIS/TK Query Processor Architecture

consists of an Application Query Processor (AQP) , a Global Query Processor (GQP), and a Local Query Processor (LQP) to interface with the query command processor (e.g. DBMS) for each information resource in the CIS.

The AQP converts an application model query, defined by an application developer, into a sequence of global schema queries, passes them on to GQP, and receives the results.

The primary query processor is the GQP. It converts a global schema query into abstract local queries, sends them to the appropriate LQPs, and joins the results before passing them back to AQP. The GQP must know where to get the data, how to map global schema attribute names to column names, and how to join results from different tables.

The LQP establishes the physical connection between the host and the appropriate remote machines where information is stored, transforms the abstract local query into the appropriate executable query commands for the remote system, sends the executable query commands to the actual processor, receives the results, and transforms the results to the standard GQP format.

The CIS/TK query processor architecture is the key to the integration of the disparate information resources [11]. It provides the platform for the logical connectivity, as discussed below.

(3) Logical Connectivity

With the query processor architecture to address the first-order and some second-order issues, we are now in a position to address the more sophisticated logical connectivity issues; for example, how to resolve the conflict of incompatible information, concept inferencing, and identification of the same instance across multiple information resources [24]. We illustrate the process of instance identification below.

Database #1 (Created by: Rich, Instructor for 564 and 579)

Name*	564	579	Sec564	Age	Perform	Address
Jane Murphy	Yes	Yes	A.M.	19	Strong	Marblehead
...						

Database #2 (Created by: Dave, head TA for 564)

Nickname*	Sec564	Performance	Sex	Major	Status	Trans	Evaluation
Happy	A.M.	Strong	F	MIS	UG	car	sharp cookie
Sneezy	A.M.	Strong	F	Fin	UG	train	Coordinator
Dopey	A.M.	Strong	F	MIS	UG	bike	hacker
Sleepy	A.M.	Strong	M	MIS	UG	car	wild card
Doc	A.M.	Strong	F	MIS	G	car	tough cookie
Grumpy	A.M.	Weak	M	?	?	?	discard
Bashful	P.M.	Good	M	MIS	G	walk	routine
...							

Figure 6 Student Databases Without Common Key Identifier

Suppose that Rich, the instructor for *Management Information Technology* (MIS 564) and *Communication and Connectivity* (MIS 579), has a database of students who take 564 and 579; while Dave, the head teaching assistant for 564, has a database for the 564 students. For some reason, Rich would like to know Dave's opinion about Jane Murphy, an instance in his student database.

As Figure 6 shows, the two databases that Rich and Dave have do not share a common key identifier for joining the data. Under this circumstance, the conventional database join technique is not applicable. The current practice requires human interaction in order to identify the same instance across databases, i.e., matching Jane Murphy from Rich's database with one of the students in Dave's database.

A moment of sharp observation would lead one to conclude that the human interaction involves the process of subsetting through common attributes to eliminate the unrelated candidate students followed by some heuristics to draw a conclusion. There are two common attributes in the two database, i.e., sec564 and performance. By applying these two attributes, the candidate students that correspond to Jane are reduced from the entire database to 5 (i.e., those who attend the A.M. section of 564 with strong performance, as shown in the first five rows of Dave's database.)

Using the other attributes in these databases, plus auxiliary databases and inferencing rules, one may come to the conclusion that Jane Murphy is "*Happy*." The logic goes as follows:

- Jane is 19 years old; therefore, the status is most likely "UG" (undergraduate) [this eliminates "*Doc*"].
- Assuming the availability of a database of typical male and female names, we can conclude that Jane Murphy is a female [this eliminates "*Sleepy*"].
- Jane lives in Marblehead. Assuming a distance database of locations of New England exists, we determine that Marblehead is 27 miles from Cambridge and therefore, it is unlikely that the transportation type is bike [this eliminates "*Dopey*"].
- Jane takes 564 and 579 which are the core courses for MIS major; therefore, it is more logical to conclude that Jane Murphy is majoring in MIS [this eliminates "*Sneezy*"].

Therefore, Jane Murphy is "*Happy*" who is a sharp cookie. Note that this analysis requires a combination of database and AI techniques.

(4) Interface Tools

To facilitate the development of such systems, a set of tools for building global schemata, application models, and application model queries are currently being developed [24]. The *Global Schema Builder* assists in the construction of a consistent global schema model. The *Application Model Builder* assists in the creation of an application model. Finally, the *User Query Builder* extends the functionality of an application model by assisting in the definition of new queries.

The *Global Schema Builder* supports the following steps: (1) representing each local database as a local component model, which directly represents the entities and attributes of that database; (2) extending the local component model by creating objects which logically represent those of the domain; and (3) creating a global integrated model which combines the objects from the local integrated models [8].

Also output from the *Global Schema Builder* are tables which are used to unify the local information resources: (1) Inter-Database Tables to specify one-to-one mappings between items in multiple local information resources; (2) Inter-Database Concept Grouping Tables to specify how concepts are related hierarchically; and (3) an Inter-Database Instance Identifier Tables to group the local join keys that are associated with a unique global instance.

Prototype Status

Taken together, the above four subsystems comprise a KIDS for delivering timely knowledge and information in a diversity of situations. The primary design goals of CIS/TK is to move responsibility from the user to the system in the following three areas: (1) physical connection to remote databases; (2) DB navigation, attribute mapping, etc.; and (3) more advanced logical connectivity issues.

An operational prototype has been developed at the MIT Sloan School of Management, as exemplified in Figure 6. Currently, the system allows for simultaneous access to relational databases in multiple machines (an IBM PC/RT and two AT&T 3B2 computers) via the LQPs. The LQPs are implemented as objects with a standard set of protocols. Physical communication details and database idiosyncrasies are encapsulated within the object. The advantage of this approach is the extendability. For instance, LQP's are currently under construction to interface the GQP with SQL/DS on an IBM 4341 accessible through a Ethernet LAN and with Reuter's Textline databases and IP Sharps' disclosure database which are neither relational nor accessible through local networks. Without modifying the existing LQPs or GQP, the CIS/TK architecture will accommodate the new LQP easily. We now turn our attention to the applicability of CIS/TK in a diversity of situations.

APPLICATION DOMAINS

Four categories of situations where a composite information system can be strategically advantageous are summarized below:

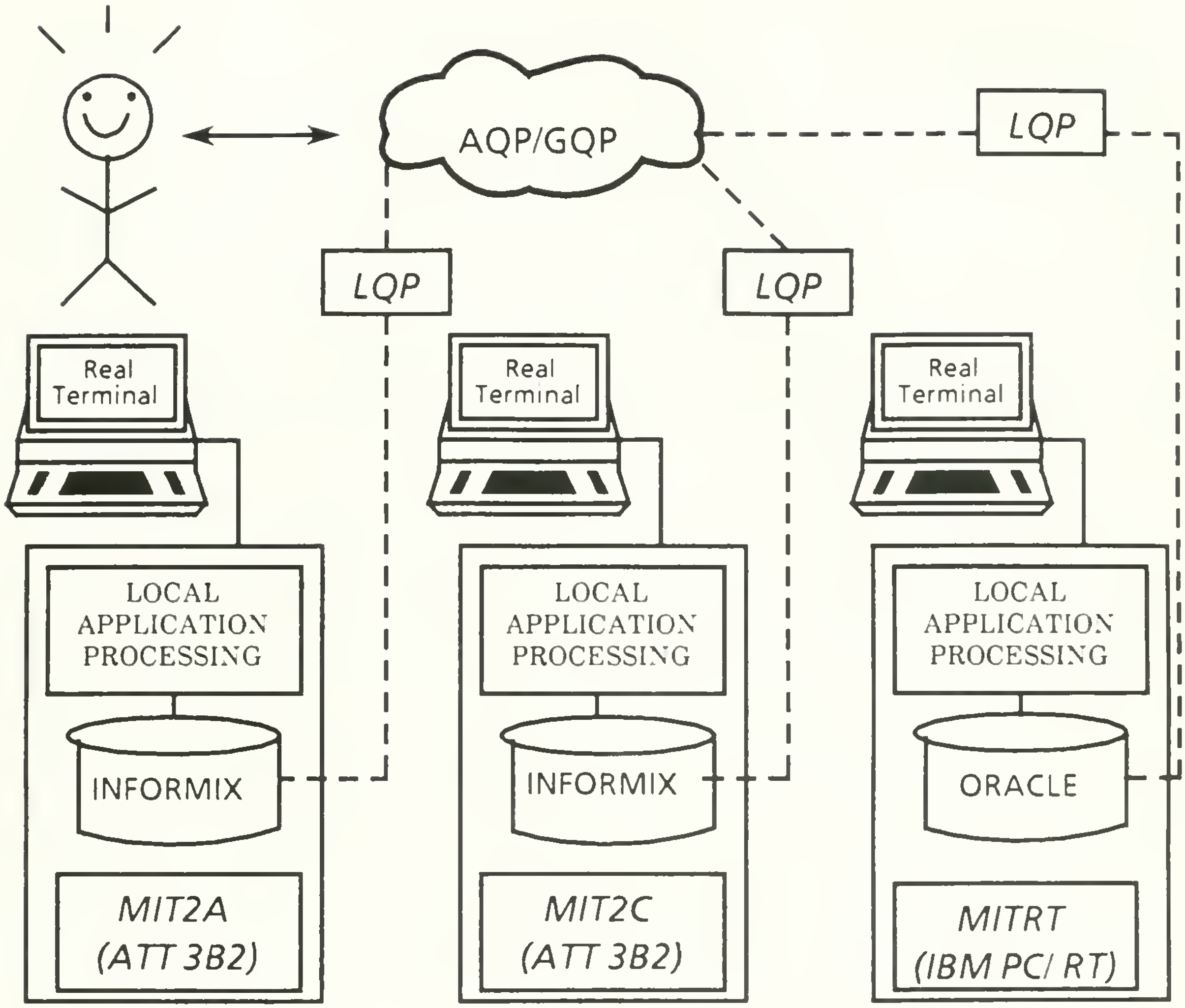

Figure 6 An Operational CIS/TK Prototype

(1) Inter-organizational - which involve two or more separate organizations (e.g., direct connection between production planning system in one company and order entry system in another company).

(2) Inter-divisional - which involves two or more divisions within a firm (e.g., corporate-wide coordinated purchasing).

(3) Inter-product - which involves the development of sophisticated information services by combining simpler services (e.g., a cash management account that combines brokerage services, checks, credit card, and savings account features).

(4) Inter-model - which involves combining separate models to make more comprehensive models (e.g., combine economic forecasting model with optimal distribution model to analyze the impact of economic conditions on distribution).

As mentioned earlier in the PAS application (Figure 1), in order to find companies interviewing at Sloan that are *auto manufacturers*, alumni/students from these companies, and recent information about these companies, all the five databases in the four organizations need to be accessed. CIS/TK can be applied to facilitate this process through its query processor architecture. Moreover, its knowledge processing component can be employed to perform complex heuristic reasoning.

The versatility of CIS/TK for a diversity of applications reflects our research perspective. A comparison of CIS/TK with some related state-of-the-art systems [1, 6, 7, 8, 10, 15, 17, 18, 23] will clarify the point, as discussed below.

The capability of the CIS/TK ensemble include: query processing facility, local database access, multiple remote database access in concert, rules and objects, instance identification facility, semantic reconciliation facility, global schema builder, application model builder, and user query builder.

Each feature per se is interesting. However, the major benefit comes from the capability of the holistic ensemble, as a result of the interfaces and tools built into the tool kit, to facilitate the delivery of timely knowledge and information to the end-user.

We compare CIS/TK with some representative products or prototypes from the related research areas: Schema Integration [1, 8], Distributed DBMSs [6, 7, 10, 15], and Object-Oriented Databases [17, 18, 23][4]. Note that none of the other systems were specifically designed for timely delivery of knowledge and information which require multiple independent disparate databases to work together within and/or across organizational boundaries, as Table 1 manifests. Therefore, it is not surprising that no single system includes the comprehensive set of capabilities incorporated in CIS/TK which are required to accomplish that goal.

CONCLUDING REMARKS

The CIS/TK ensemble is a unique and innovative system for delivering timely knowledge and information in an inter-organizational setting. In the rapidly changing, complex, and competitive global market, the capability to dynamically align corporate strategy with information technology in the organizational context is a critical issue facing the executive. CIS/TK is aimed at providing such a dynamic IT platform for supporting knowledge and information intensive applications.

Our focus is on real, nontrivial, and exciting problems challenging today and tomorrow's IS executives. The operational prototype we have implemented clearly demonstrates the feasibility of such an innovative concept. In the near term, we plan to extend the system through the following tasks: (1) design and implement facilities for credibility analysis, conflict resolution, and further concept inferencing; (2)

---

4. Also private communications with researchers at CCA on MULTIBASE and PROBE, and Ontologic, Inc. on Vbase.

develop more efficient local query processors and communication servers; and (3) demonstrate the feasibility of CIS/TK to interface with geographically disparate off-the-shelf products or customized systems, such as Reuter's Dataline, Textline, and Newsline databases. We believe that this effort will not only contribute to the academic research frontier but also benefit the business community in the foreseeable future.

Table 1 Comparing CIS/TK with Related Systems

RESEARCH AREA		Schema Integration	Homogeneous DDBMS	Heterogeneous DDBMS	OODB	OODB	OODB
EXAMPLE	CIS/TK	Elmasri, Navathe	INGRES* SQL*STAR	MULTIBASE	PROBE	POSTGRES	VBASE
Query Processing	Yes	No	Yes	Yes	Yes	Yes	Yes
Local DB Access	Yes	No	Yes	Yes	Yes	Yes	Yes
Multiple Remote DB Access	Yes	No	Yes	Yes	Yes	No	No
Objects	Yes	No	No	No	Yes	Yes	Yes
Rules	Yes	No	No	No	No	Yes	No
Data Mapping Facility	Yes	Yes	No	No	No	No	No
Instance Identification facility	Yes	No	No	No	No	No	No
Global schema facility	Yes	Yes	Yes	Yes	No	No	No
Global Schema Builder	Yes	Yes	No	No	No	No	No
Application Model Builder	Yes	No	No	No	No	No	No
User Query Builder	Yes	No	No	No	No	No	No
Organizational data policy	Planned	No	No	No	No	No	No
Strategic goals	Planned	No	No	No	No	No	No
Features that CIS/TK does not focus		Automate Integration	Commercial Availability	demonstrate feasibility	PDM based	Active DB Demons	Commercial Efficiency

REFERENCES

1. Batini, C. Lenzirini, M. and Navathe, S.B. A Comparative Analysis of Methodologies for Database Schema Integration. ACM Computing Surveys, Vol. 18, No. 4, (December 1986), pp. 323 - 363.

2. Benjamin, R.I., Rockart, J.F., Scott Morton, M.S., and Wyman, J. Information technology: a strategic opportunity. Sloan Management Review, Vol. 25, No. 3, (Spring 1985), p. 3-10.

3. Benson, R.J. and Parker, M. M. Enterprise-Wide Information Management: An Introduction to the Concepts. IBM Los Angeles Scientific Center, G320-2768, (May 1985).

4. Cash, J. I., and Konsynski, B.R. IS Redraws Competitive Boundaries. Harvard Business Review, (March-April 1985), 134-142.

5. Clemons, E.K. and McFarlan, F.W., Telecom: Hook Up or Lose Out. Harvard Business Review, (July-August, 1986).

6. Dayal, U. and Hwang, K. View Definition and Generalization for Database Integration in Multidatabase System. IEEE Transactions on Software Engineering, Vol. SE-10, No. 6, November 1984, pp. 628-644.

7. Deen, S. M., Amin, R.R., and Taylor M.C. Data integration in distributed databases. IEEE Transactions on Software Engineering, Vol. SE-13, No. 7, (July 1987) pp. 860-864.

8. Elmasri R., Larson J. and Navathe, S. Schema Integration Algorithms for Federated Databases and Logical Database Design. Submitted for Publication, 1987.

9. Frank, W.F., Madnick, S.E., and Wang, Y.R. A Conceptual Model for Integrated Autonomous Processing: An International Bank's Experience with Large Databases. Proceedings of the 8th Annual International Conference on Information Systems (ICIS), (December 1987), pp. 219-231.

10. Goldhirsch, D., Landers, T., Rosenberg, R., and Yedwab, L. MULTIBASE: System Administrator's Guide. Computer Corporation of America, Cambridge, MA, (November 1984).

11. Horton, D.C. An Object-Oriented Approach Towards Enhancing Logical Connectivity in a Distributed Database Environment. Master's Thesis, Sloan School of Management, MIT, (May 1988).

12. Ives, B. and Learmonth, G.P., The Information Systems as a Competitive Weapon. Communications of the ACM, Vol. 27(12), (December 1984), pp. 1193-1201.

13. Kerschberg, L. Ed. Expert Database Systems, Proceedings from the First International Workshop. The Benjamin/Cummings Publishing Company (1986).

14. Levine, S., Interfacing Objects and Database. Master's Thesis, Electrical Engineering and Computer Science, MIT, (May 1987).

15. Lyngbaek, P. and McLeod D. An approach to object sharing in distributed database systems. The Proceedings of the 9th International Conf. on VLDB, (October, 1983).

16. Madnick, S.E. and Wang, Y.R. Evolution Towards Strategic Applications of Databases Through Composite Information Systems. To Appear in the Journal of Management Information Systems, (Fall, 1988).

17. Manona, F. and Dayal, U. PDM: An Object-Oriented Data Model Proceedings International Workshop on Object-Oriented Database Systems. Pacific Grove, CA. (September 1986) pp. 18 - 25.

18. Ontologic Inc. Vbase Integrated Object System. 47 Manning Rd., Billerica, MA 01821 (November 1987).

19. Porter, M. and Millar, V.E., How information gives you competitive advantages. Harvard Business Review (July-August 1985) p. 149-160.

20. Rincon, M. N., Integrating systems for financial institutions services using Composite Information Systems. Master's Thesis, Sloan School of Management, MIT, (May 1987).

21. Rockart, J.F. and Scott Morton, M.S., Implications of changes in information technology for corporate strategy. Interfaces, Vol. 14, No. 1 (January-February, 1984), pp. 84-95.

22. Stefik, M. and Bobrow, D.G. Object-Oriented Programming: Themes and Variations. The AI Magazine, Vol. 6, No. 4, (Winter 1986), pp. 40 - 62.

23. Stonebraker M. and Rowe, L.A. (ed) The POSTGRES Papers. No. UCB/ERL M86/85 (June 1987) UC Berkeley, 94720.

24. Wang, Y.R. and Madnick, S.E. Facilitating Connectivity in Composite Information Systems. To Appear in ACM Database.